SHIP PRODUCTION COMMITTEE
FACILITIES AND ENVIRONMENTAL EFFECTS
SURFACE PREPARATION AND COATINGS
DESIGN/PRODUCTION INTEGRATION
HUMAN RESOURCE INNOVATION
MARINE INDUSTRY STANDARDS
WELDING
INDUSTRIAL ENGINEERING
EDUCATION AND TRAINING

November 1993
NSRP 0408

THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

1993 Ship Production Symposium

Paper No. 4: Integrated Ship Design and Its Role in Enhancing Ship Production

U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
NAVAL SURFACE WARFARE CENTER

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **NOV 1993**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **The National Shipbuilding Research Program, 1993 Ship Production Symposium Paper No. 4: Integrated Ship Design and Its Role in Enhancing Ship Production**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Surface Warfare Center CD Code 2230 - Design Integration Tower Bldg 192 Room 128 9500 MacArthur Blvd Bethesda, MD 20817-5700**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**12**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

DISCLAIMER

0408

THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

1993

SHIP PRODUCTION SYMPOSIUM

Sponsored by the Hampton Roads Section
Society of Naval Architects & Marine Engineers

CENTENNIAL
1893-1993

Williamsburg Virginia, November 1-4, 1993

CENTENNIAL 1893-1993

The National Shipbuilding Research Program
1993 Ship Production Symposium
Sponsored by the Hampton Roads Section SNAME

Integrated Ship Design and Its Role in Enhancing Ship Production

Jonathan M. Ross **(M)-Ross-McNatt Architects**

ABSTRACT

This paper focuses on an important trend that is increasing shipbuilding productivity: integrating the computer-aided ship design process The ship design process is increasingly being performed with the help of computer programs, either individual programs that address single aspects of the design or integrated programs comprised of modules that address a range of ship design aspects. In the case of integrated computer programs, the ship design process is enhanced through individual program modules sharing their results with each other, preferably from a common database. Modem integrated ship design programs not only improve the efficiency of ship design, they also improve the efficiency and ease of ship production from lofting and numerical cutting to providing workshop drawings and production information.

NOMENCLATURE

CAD	Computer Aided Design
CAE	Computer Aided Engineering
CAL	Computer Aided Lofting
CAM	Computer Aided Manufacturing
CAPP	Computer Aided Process Planning
DXF	Data exchange Format (proprietary to Autodesk Inc.)
ESPRIT	European Strategic Program for Research and Development in Information Technology
IGES	initial Graphics Exchange Specification
NC	Numerical Control
PC	Personal Computer
STEP	Standard for the Exchange of Product data
VLCC	Very Large Crude Carrier

INTRODUCTION

The integrated ship design program is a compelling concept and one whose time has come. It aims to digitize the traditional ship design 2-D drawings, bills of materials and schedules carry out complex design calculations; and, perhaps most importantly, advance the ship design process into the multi-user environment and provide the designer and the production shipyard with a full-ship, 3-D database. The advantages of an integrated ship design program include decreased design hours, reduced lead time, increased productivity, early detection of interferences, ease in making changes, a drastic reduction of information errors, and the availability of production-oriented data. The purpose of this paper is to introduce examples of integrated ship design programs, show how those programs achieve their high degree of integration% and describe how integrated ship design programs enhance ship production.

EXAMPLES OF INTEGRATED SHIP DESIGN PROGRAMS

Eight integrated ship design programs are presented in the paragraphs that follow HULLTECH, AutoSHIP System, FORAN, HICADEC, lMSA, TRIBON, NAPA and NAVSEA CAD-2. They area representative sample of today's state-of-the-art integrated ship design programs. Information on the programs was obtained from interviews, sales literature and correspondence with the organizations that have developed the programs. The programs, or at least the modules from which the programs are comprised, have been developed over a period of years and, without exception, are still being improved. Different programs focus on different phases of the design/production sequence, as illustrated in Figure 1.

HULLTECH

HULLTECH is the latest generation of ship design software from the BMT Group (formerly the British Ship Research Association), which has been involved in the development of computer-aided ship design and production software for over 25 years. HULLTECH is a follow-on to BRITSHIPS 3.

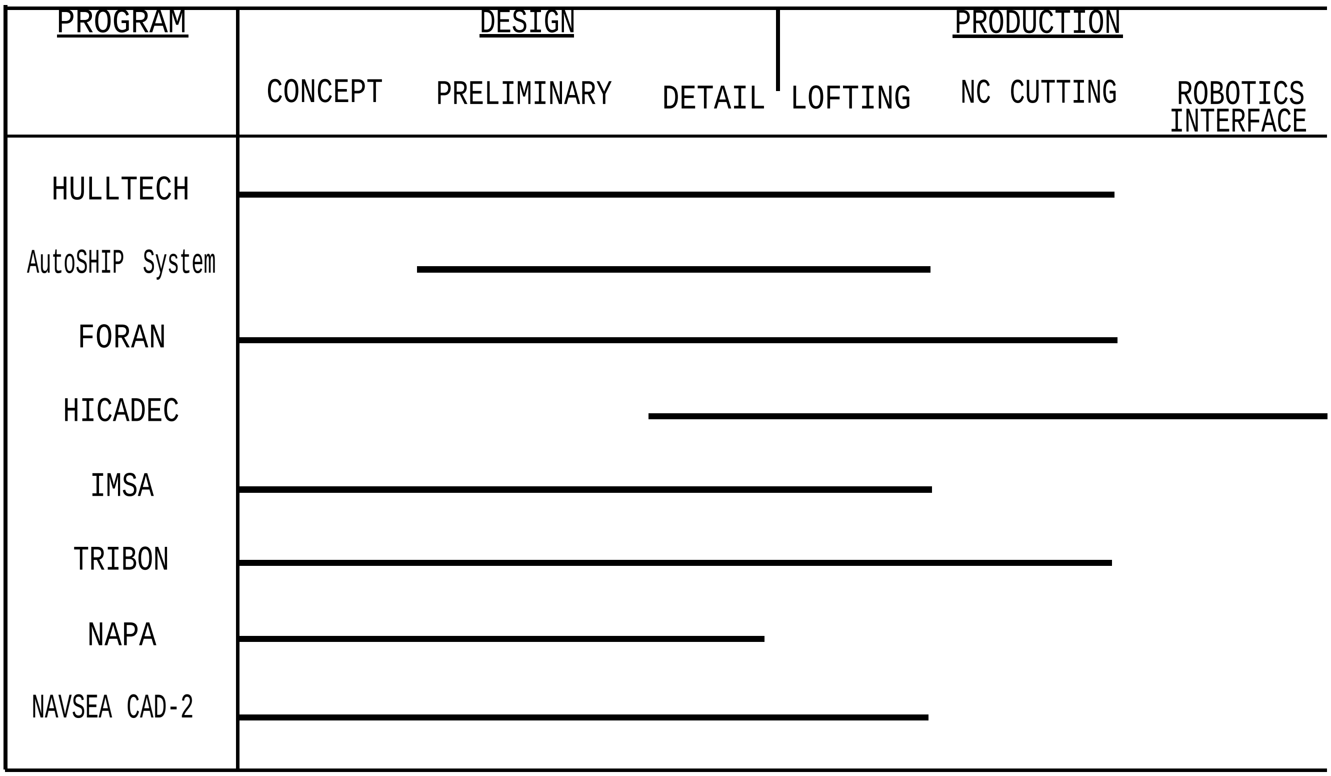

Figure 1 - Ship Design Programs' Focus in the Design/Production Sequence

HULLTECH supports the ship design process from initial concept design to providing production information. The software, initially written to run on mainframes, is now widely available on UNIX workstations and personal computers (PCs) as a result of a policy of open systems programming and portability. The software is presently being adapted for use on MS-Windows for the PC and X-Windows/Motif for workstations (38).

HULLTECH covers a wide range of shipbuilding-specific applications for designers and production engineers, including hull shape design, arrangements, lines development hydrostatics, stability, longitudinal strength, resistance and power, seakeeping and maneuvering, shell plate and internal steelwork definition, as well as plate nesting and cutting information for production. The generic application areas such as drafting, pipework, and structural analysis, are covered by third partly software for which BMT provides direct interfaces. Some of the third partly software supported includes Microstation, AutoCAD or ComputerVision for the drafting functions, CADMATIC or Computer Vision for the piping and plant modeling functions, and MAESTRO, ANSYS or PATRAN for the structural analysis (1, 2, 3, 4, 38).

AutoSHIP System

Coastdesign, formed in 1980, is a Canadian company. Its ship design program, the AutoSHIP System, is applicable from the preliminary design stage through lofting, with capabilities in the areas of hull definition and fairing, weights, stability, hydrostatics, longitudinal strength, resistance, and power. Developed for use by small and mid-sized yards, the program aims to be user friendly and can run on PCs. The program is scheduled to run entirely on Windows by mid-1993 (5, 6, 7, 8).

FORAN

FORAN is a computer aided design/ computer aided manufacturing/computer aided engineering (CAD/CAM/CAE) ship design and production system developed by the Spanish company Senermar. The program FORAN is written in the English language and may be run on UNIX and VMS operating systems

and with X-Windows and OSF/MOTIF. The latest version, FORAN V30, covers all the aspects of general design, drafting, steel structure, machinery and outfitting design and production. More than 100 shipyards in 19 countries have been licensed to use FORAN (9, 10, 34).

HICADEC

HICADEC is the outgrowth of systems developed in Japan by Hitachi Zosen Corporation which were first used in the 1960s. HICADEC has been in use since 1986 and is more powerfull and user friendly than its predecessors. This program, which runs on UNIX workstations, is available under X-Windows, HICADEC addresses the integrated CAD/CAM design of ship structure, piping, outfitting, and electrical design through the use of a three-dimensionally processed database. The system also provides input to support robotic ship production tasking, described in a following section. In additio, the HICADEC system is designed to make extensive use of standards. At Odense Steel shipyard, the marketing agent for the system in the West and co-developer of the HICADEC system in use at the Odense yard, the Danish shipbuilding standards have been incorporated (11, 37).

IMSA

IMSA, or International Marine Software Associates, is a cooperative venture being carried out by several American firms to integrate five existing programs into modules of an integrated ship design program. The program has capabilities in hull design, propulsion design and analysis, hydrostatics, stability, structural design and analysis, lofting, and support for numerical cutting. The IMSA programs run on workstations and PCs (12, 13).

TRIBON

Kockums Computer Systems (KCS) has refined and marketed three integrated design programs worldwide AUTOKON, STEERBEAR and SCHIFFKO. Each of these programs was developed independently, beginning in the sixties. The programs run on International Business Machines (IBM) or Hewlett Packard (HP) workstations and are used during the final design and production stages for ships and offshore structures. They provide capabilities in the areas of steel design and production, lines fairing, piping, cableways and ventilation design (14, 15, 16).

In mid-1993, KCS introduced a new program called TRIBON. It contains selected features from all three of the present programs and builds on the technology of STEERBEAR. TRIBON has applications for hydrostatics, stability, longitudinal strength, lines fairing, steel design, piping, cabling, ventilation, foundation and accommodations, as well as production information. TRIBON is coded in Unix C++ and will run on a DEC VAX/VMS workstation. Later versions will run on HP and, if customer demand warrants, IBM workstations. TRIBON will be upward compatible from its present three programs, which will continue to be supported (16, 25).

NAPA

NAPA (the Naval Architectural PAckage) is a computer-aided ship design program developed in-house by Wartsila Corporation beginning in 1976. It builds upon ship design software experience developed in the Wartsila Helsinki Shipyard from the 1960s. The program is now maintained and marketed by the independent company Napa Oy. It was first used productively by Wartsila in 1982, and since 1984 has been sold to outside companies, including many of the major European shipyards and Det norske Veritas Classification A/S. The program is written in FORTRAN 77 and runs on a variety of computers, including Sun, VAX and HP Workstations, and 486 PCs. NAPA is used from the early stages of design through detail design, and, following construction, for development of a ship's documentation. Capabilities include general arrangements, capacity lists, hull form design and fairing, lofting, intact and damage stability, container loading, grain stability, weight and cost calculations, longitudinal strength, launching, resistance and power, seakeeping, and maneuvering (17, 18,19,20,21,22, 36).

NAVSEA CAD-2

NAVSEA CAD-2 is a relatively recent initiative being carried out by Intergraph Corporation under contract to the Naval Sea Systems Command (NAVSEA). It provides CAD/CAM systems and services to support the design, construction, maintenance, overhaul, alteration, and repair of Navy ships and shipboard systems. The eight-year software development and implementation effort was begun in 1991. CAD-2 is run on UNIX-based workstations. The organization of CAD-2 is reflected in Intergraph's Vehicle Design System (VDS), the commercial version of the program. VDS is comprised of three modules,

encompassing equipment design, structural systems design, and a routing package that includes piping, HVAC, and electrical raceway design (23, 24).

One thrust of the effort is to develop interfaces between existing ship design programs that NAVSEA has procured or developed and a single product model. That is, existing programs, such as SHCP, are not made part of CAD-2, but their information requirements and data transfer capabilities are being addressed by CAD-2. Certain existing programs may be updated as part of NAVSEA's overall approach to computerizing the ship design process, but fill integration of ship design programs into CAD-2 is not envisioned in order to continue to encourage vendor competition. CAD-2 will be ported to run on X-Windows. An example of a program that is already ported into X-Windows is SPIFFY, a structural section analysis program, which calculates section properties and certain non-graphic attributes (e.g., weight) of a sectional cut through an Intergraph CAD model of a Ship (24).

INTEGRATION

The ultimate goal of integrated ship CAD/CAM is the total integration of all processes, from early design through production. Although many U.S. shipbuilders have made investments of millions of dollars in CAD/CAM systems, the various aspects of the systems tend not to be integrated with each other. For example, a shipyard may have one CAD system for structural design and a different CAD system for outfitting design. Additional aspects, beyond design, that could be integrated with the design process include Computer Aided Process Planning (CAPP) and robotics.

Integration of a ship design program maybe viewed from two levels:

- Integration among the modules of a ship design program is the most basic level of integration. This level of integration means that the various modules of a program are designed to communicate and share data with one another to at least some extent. User interfaces may differ, and commonly this type of program cannot support combining results from among the various modules to make a unified presentation of the results. This level of integration is characterized by some as an interfaced system rather than an integrated system (36).
- The more advanced level of integration is by means of a product model, which is a detailed, three-dimensional description of the ship and its major systems. The product model is a common database that is shared by all the modules; that is, there is no need for data conversion among the modules.

Usually is there is a single user interface. These two levels are discussed in the following paragraphs, and examples are provided from the integrated ship design programs described above. It must be stressed that the examples are illustrative and not all-inclusive; that is, if one program is used as an example to illustrate a certain future, that does not mean that other programs also have the same feature. Space constraints and the complexity of the programs themselves prevent a fill listing of features or a detailed comparison among the programs.

Integration Among Modules

Typically, when a ship design program is synthesized from a number of previously separate programs, the first step is to provide integration among modules as a means to provide the data from initial steps in the design process as input to follow-on steps. The data is stored in different databases or datastores, each of which may have different format and access conventions. One advantage of integration among modules and separate databases (one for each module) is that other, independently-developed modules may be added without having to expensively modify the new module to conform to the format of the existing program. This provides flexibility to quickly incorporate new capabilities, and thus upgrade the existing program.

In HULLTECH, modular and modeling information is stored using direct access binary datastores appropriate to each application. Datastore accession is direct where appropriate to obviate intermediate file data transfer. For example, the hullform generation system creates geometry that can be immediately analyzed by the naval architecture package (4). In the case of the AutoSHIP System, the modules communicate by intermediary files resident on a single directory. Within the Windows® environment, Dynamic Data Exchange maybe used, and there are extensive cut and paste capabilities (especially useful in report generation). IMSA facilitates computer-based interfacing of its five modules with each other and with third party programs, and has established a common data specification called IDF or IMSA Definition File. This file is open (i.e., published) in order to make the

development of interfacing easy for third party programs. Thus, the user can choose which program to use for each application (IMSA or third party) with the knowledge that data can be shared between programs (35).

Product Model

A product model is an integrated database of an entire ship that supports the informational needs of engineering, design, and production. Early versions of this concept were usually tailored to a specific project, and were not broadly enough based to address the general integration of design data and process information that together define a ship. More modem versions of the concept are tailored to ship design and production, yet are general enough to be used for different ship projects. The NEUTRABAS product information model, under development by the European Strategic Program for Research and Development in Information Technology (ESPRIT) Project, is an example of this type product model (27).

TRIBON is based on the concept of creating a three-dimensional database product model of a ship or platform. This product model is the source for technical and administrative information, including drawings, weights, NC data, parts lists, stiffener lists, piping, and materials (28, 25). Presently, Coastdesign, is developing its version of the product model, called the Single Vessel Definition, which will allow one basic vessel definition to be used from the earliest stages of the design process through to the final manufacturing phase in the AutoSHIP System (29). The developers of FORAN view integration as perhaps the most important aspect to be considered in their ship design program. The FORAN product model is topological, that is, it includes not only the definitions of the various ship elements themselves but also logical connections to other, related, elements. With this approach, a change to one element automatically generates changes to related elements (9, 26, 34). The NAVSEA CAD-2 system also has a product model capability. Key to the success of that product model are its parametric libraries, in which every part, from pipe to foundations, is composed of intelligent macros, enabling them to be tracked and put together into their design assemblies (23, 30).

In NAPA a product model of a ship (called a ship model by NAPA) is created and updated to form an organized, uniform source of design information. This model addresses general arrangements, compartmentation, tank lists, and capacities. The model can provide any parameters that are related to the ship model or parts of the model. For example, the user can select a subset of objects that the model tracks, and receive data relating to that subset such as volumes, areas, or centers of gravity (21, 36).

Related Considerations

Related considerations for integrated ship design programs include flexibility for future growth, technical excellence of the modules, communication with other programs, and making the programs user friendly. Flexibility for the future has been noted as an advantage of a program that uses separate databases for each of its modules (although the use of separate databases has disadvantages as well in regard to user friendliness and efficiency of operation). The need for flexibility, even within common database and product model types of ship design programs, is recognized by a number of program developers.

Technical excellence in the modules of ship design programs is another area of focus. Technical excellence forms the foundation on which the validity and usefulness of the programs are based. An example of technical excellence is found in MAESTRO, a module in the IMSA program. MAESTRO carries out structural finite element analysis, failure mode evaluation and multi-objective optimization. The program applies to ships, advanced and high performance vehicles, offshore structures and submarines. MAESTRO has been successfully validated against other programs and physical experimental results, and is in use worldwide.

Communication with other vendors' programs and databases is of increasing importance in today's environment of computer-based information exchange. This kind of communication is important in the shipbuilding environment when, for example, the contract design is produced with a ship design program that is different from the one on which the final design is to be developed. HULLTECH interfaces include IGES, DXF, and PATRAN (38). The AutoSHIP System interfaces with other programs through Data exchange Format (DXF) and Initial Graphics Exchange Specification (IGES). FORAN software can interface with other systems using DXF, SIF, IGDS and HPGL formats (31). As noted above, IMSA has published its common data specification, IDF, as a means to foster communication with other programs. HICADEC communicates with other CAD systems using DXF and IGES, and is linked to BMT Hullsurf, NAPA, among others (37). IMSA output and input may be in various formats, including DXF, SHCP and IGES. KCS' USS is designed to be open by providing

DXF and IGES interfaces and communication capabilities with the STandard for the Exchange of Product data (STEP) Program. It provides input to Det norske Veritas for classification. Over 20 interfaces are available to and from NAPA, including IGES, VDAFS (German Standard DIN 66301), DXF, MEDUSA SCHIFFKO, AUTOKON, TRIBON and a direct on-line link to STEERBEAR (25, 36). CAD-2 interfaces include IGES, CALS-IGES and DXF. STEP will be addressed also (30).

A final consideration is making programs user friendly. For example, a user friendly feature in the IMSA module FAST SHIP is in the area of hull design, where a designer works interactively with the computer and “sculpts” surfaces of the hull. In this way, the designer watches the hull shape change dynamically as control points are moved in three dimensions. The program also carries out hydrostatic calculations, giving the designer immediate feedback that target hydrostatic values are being matched (12, 13). To help make NAPA user friendly, emphasis has been placed on enhancing the user interface through ease of learning how to use the system on-line help functions and an interactive, command driven format. NAPA’s flexibility in use, excellent graphics and uniform user interface, and the totally integrated modem structure, in short, its ability to be user friendly, formed the basis for a major classification society choosing NAPA as its naval architectural program (19). Other programs also have features that help make them user friendly.

ENHANCING SHIP PRODUCTION

A powerful potential advantage of integrated ship design programs is that the data generated during the design process can be tailored in format and content so that it can help support the ship production process. Virtually all of the programs described above provide at least some input to the ship production process, and several programs provide significant input.

HULLTECH uses interactive facilities and computer graphics to provide shell plate surface curves (e.g., seams, butts and longitudinal traces), and a breakdown into individual plates for their development complete with all marked-on lines (2-dimensional definition, green, minimum rectangle, sight line templates, and pin-jig bed). HULLTECH also provides relevant production information for shop floor personnel and information that supports interactive nesting and automatic NC path generation. Inverse frame-line bending data is included for both longitudinals and transverses (32). CAD-2 support to the production process includes plate nesting capabilities (including the ability to address doubly contoured plate, and to include NC cutting lines as well as sight lines) and NC pipe bending and production instructions (30). Coastdesign plans to extend its AutoSHIP System capabilities to defining shapes, but not to NC cutting and robotics, preferring to leave those functions to third-party systems (8).

FORAN provides information for use in steel production, and in machinery and outfitting production. In the case of machinery and outfitting production, FORAN’s capabilities include automatic 3-D generation of fittings as parametric objects; equipment 3-D solid modeling layout of equipment, ducts, cable trays, piping, and similar systems with respect to the steel structure or any other component full integration of diagram information with the 3-D module definition, on-line interference detection, and, finally, the generation and handling of manufacturing and assembly documents, from parts lists to bills of materials (9).

HICADEC places great emphasis on supporting the ship production process, with information provided to name, describe and specify exact cutting and assembly operations to the level of individual parts. Odense Steel shipyard has used HICADEC on several recent commercial new construction projects. On these projects the system automated the production of steel detail and outfitting fabrication and assembly drawings; automated the detail planning and budgeting for steel work and automated material takeoff and requisitioning. It also created a structural database from which the automated welding programs for a series of very large crude carriers (VLCCS) (prepared by one person) which resulted in the automated weldlng of 100% of the midbody sections by Odense welding robots (33).

IMSA’S modules ShipCAM and NC-PyrosLofting address development of the table of offsets through all stages of fairing and lofting to the NC code for computerized plate burning. The program is interactive, and all surfaces can be expanded to flat plate with all markings for frames, stringers, bulbs, or thrusters.

KCS’ TRIBON provides tools to plan the assembly stage of production for hull and outfit items. The TRTIBON structural system handles comprehensive bracket generation, nesting of plate parts, workshop drawings and production information, parts and profile lists, templates for bending plates and stiffeners, and assembly jig data. TRIBON’S outfitting system covers standard material and specification libraries, schematic diagrams, equipment definition and location, modeling of pipes, cableways and ventilation ducts, isometric

drawings, material lists for prefabrication and assembly, weld records, NC bending data, interference control, weight and center of gravity calculations, and composite drawings. The electrical modules cover the areas of cable specification and registration, equipment definition and location, cableway registration, automatic routing of cables, and installation instructions and feedback.

CONCLUSIONS

Integrated ship design programs, based on experience and lessons learned since initial applications in the 1960s, are providing real-world enhancements to ship production and, as improvements are continually added, will continue to do so. The trends include further integration through product models, enhanced communication with third party programs, increased user friendly interfaces, and the extension of program capabilities into early stages of design and into production.

REFERENCES

1. 'Overview of BMT Software for Marine Applications, 'BMT ICONS Limited, Wallsend Research Station, Wallsend, Tyne and Wear, England.
2. 'Conceptual Design and Tendering Software,' BMT ICONS Limited, Wallsend Research Station, Wallsend, Tyne and Wear, England.
3. Telephone Conversation with Graham Marshall (BMT ICONS Limited), April 8, 1993.
4. Fax Message from Graham Marshall (EMT ICONS Limited), April 15, 1993.
5. Coastdesign Marine Software Product, Surrey, B.C. Canada, May 15, 1992.
6. AutoSHIP System, The Industry Standard, Coastdesign, Surrey, D.C. Canada.
7. AutoCLASS, Coastdesign.
8. Telephone Conversation with Grahame Shannon (Coastdesign), April 1, 1993.
9. Letter from E. Martinez-Abarca (Senermar), April 14, 1993.
10. 'Shipyard Week - Senermar Turns to UNIX to Widen Market,' *Lloyd's List*, February 3, 1993.
11. Inoue, Takehiko, Hirotaka Shirakami, Kunihiko Shishida, Younosuke Moriya, "HICADEC: Integrated CAD/CAM System With 3D Interactive Data Processing Architectures for CIMS in Shipbuilding," *Computer Applications in the Automation of Shipyard Operation and Ship Design, VI*, D. Lin, Z. Wang and C. Kuo (editors), Elsevier Science Publishers B.V. (North-Holland), IFIP, 1989.
12. IMSA, International Marine Software Associates, Durham, NH.
13. 'Proposal to Develop an Integrated Ship Design Optimization Tool (ISDOT), Technical Proposal, Volume I,' Ross-McNatt Naval Architects, Annapolis, MD, November 6,1992.
14. Kockums Computer Systems is Your Long Term Partner, Kockums Computer Systems AB, Malmo, Sweden, 1990.
15. AUTOKON, Kockums Computer Systems AB, Malmo, Sweden, 1989.
16. Meeting with Ove Eng (Kockums Computer Systems), Washington, DC, March 26, 1993.
17. NAPA Documentation/Main System/General, System Functions of NAPA, Napa Oy, J. Saarilahti, 1991.
18. 'New Company for the Challenges of the 90s,' *Shipping World & Shipbuilder*, p. 30, January/February 1990.
19. 'NAPA for Det norske Veritas,' *Schiff & Hafen/SEEWIRTSCHAFT*, Heft 8, p. *39*, 1991.
20. Telephone Conversation with Ilmo Kuutti (Napa Oy), April 5,1993.
21. Kuutti, Ilmo, "NAPA, The Naval Architectural Package for Professionals," Napa Oy, November 18, 1991.
22. 'NAPA, The CAE system for Basic Ship Design,' *Shipping World & Shipbuilder*, October 1989 [check this date].
23. Donovan, Rick, "NAVSEA CAD-2 1993 Program Status and Highlights; Full Speed Ahead in a Successful Transition," Intergraph Corporation, Federal Systems Division, March 1993.
24. Telephone Conversation with James Murphy (Naval Sea Systems Command), April 1, 1993.
25. Fax Message from Ove Eng (Kockums Computer Systems), June 17, 1993.
26. 'FORAN V30, The Way to CIM from Conceptual Design in Shipbuilding,' Senermar, Sener Sistemas Marines, S. A., Madrid, Spain.
27. Welsh, M., J. Lynch, and P. Brun, 'A Data Model for the Integration of the Pre-commissioning Life-cycle Stages of the Shipbuilding Product; The Society of Naval

Architects and Marine Engineers 1991 Ship Production Symposium, San Diego, CA, September 3-6, 1991.
28. Letter from Henrik Bucher (Kockums Computer systems AB) to Tobin R. McNatt (Ross-McNatt Naval Architects) dated February 4, 1992.
29. Shannon, Grahame, 'Visions of the Future,' *Productivity Tips*, Volume 1, Issue 1, Coastdesign, Surrey, B. C., Canada, May 1992.
30. Telephone Conversation with Stephen Klomparens (Intergraph Corporation), April 5, 1993.
31. 'Sotftware Suppliers Seek Increased Integration,' The Motor Ship, p. 56, April 1993.
32. BMT ICONS Brochure, BMT ICONS Limited, Wallsend Research Station, Wallsend, Tyne & Wear, England.
33. Martin, Doug, 'Acquire, License to U.S. Shipbuilders and Support the HICADEC Shipbuilding CAD/CAM System,' 1993 NSRP Project Abstract, November 30, 1992.
34. Fax Messages from E. Martiniz-Abarca (SENERMAR), June 15,1993.
35. Fax Message from Bruce Hays (Design Systems & Services, Inc.) to Tobin R. McNatt (Ross-McNatt Naval Architects), June 7, 1993.
36. Fax Message from Ilmo Kuutti (NAPA Oy), June 21, 1993.
37. Fax Message from Torben Andersen (Odense Steel Shipyard, Ltd.), June 22, 1993.
38. Letter from Chris. J. Lloyd (BMT ICONS Limited), June 16, 1993.

Additional copies of this report can be obtained from the
National Shipbuilding Research and Documentation Center:

http://www.nsnet.com/docctr/

Documentation Center
The University of Michigan
Transportation Research Institute
Marine Systems Division
2901 Baxter Road
Ann Arbor, MI 48109-2150

Phone: 734-763-2465
Fax: 734-763-4862
E-mail: Doc.Center@umich.edu